Methods for Locating Legacy Wells
Onshore Unconventional Resources FWP

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Presentation Outline

• Project Overview- Well Locating Activities
  – Aeromagnetic surveys – challenges/results/findings
    • Private Marcellus Site (western PA)
    • Hillman State Park
    • Oil Creek State Park
    • Susquehannock State Forest
  – Fieldwork
    • Verification/validation of results
    • Evaluation of current inventories/databases
    • Site selection for other monitoring Team activities (fugitive methane measurements from unplugged, leaking wells)
  – Evaluation of miniaturized sensors deployed by UAS
    • MFAM
Benefit to the Program

• Unmapped, unplugged abandoned wells represent the greatest environmental risk from hydraulic fracturing

• Rapid and cost-effective methods to locate abandoned wells will allow operators to mitigate environmental risk
Project Overview: Goals and Objectives

• Develop rapid and cost-effective methods for locating legacy wells.
  – Use public information that is widely available at low or no cost.
  – Use airborne methods that are rapid, can be applied to areas with terrain and vegetation challenges, and avoid landowner issues
  – Provide a complete catalog of existing well locations at test sites
Technical Status

- Project has met all initial goals;
- New, tougher goals have been established
  - Methods are currently being optimized to be effective for the most challenging wells
  - Well location survey costs are being reduced by the incorporation of UAV
Methods for Locating Legacy Wells

Garret Veloski, Richard Hammack, James Sams
Salt Creek Oil Field
Midwest, Wyoming
2005

- Operator planned CO₂ flood (EOR)

**Approach**

- Helicopter survey using two boom-mounted magnetometers
- Detects the unmistakable “bull's-eye” magnetic signature of vertical steel well casing
Results from Test Area

- Method located 100% of wells drilled for primary production (1912-1926)
- Method located 82% of wells drilled for secondary recovery (water flood, 1965-1990)
- Based on success locating old wells at test area, operator used helicopter method to survey entire oilfield (43 mi²)
Legacy Wells in Pennsylvania

- >150,000 wells recorded in PA Internet Record Imaging System Wells Information System (PAIRIS/WIS) + paper records > 330,000(?) wells
- Many unrecorded, orphaned or otherwise abandoned and/or unmarked, unplugged or improperly plugged
- Location data suspected to be inaccurate
- No casing required prior to 1921
- No registration required prior to 1955
- No drilling permits or bonds for abandonment, no specific plugging requirements prior to 1984
Helicopter Magnetic and Methane Surveys of PA State Lands with Legacy Oil and Gas Wells

Project Locator Map
Airborne Magnetic and Fugitive Methane Survey Areas
Hillman State Park
Oil Creek State Park
Susquehannock State Forest, Potter County
Gas Transmission Pipeline, Potter & Clinton County
Marcellus Well Site (private land)
Pennsylvania Internet Record Imaging System
Wells Information System (PAIRIS/WIS)
Well Locations

- Susquehannock State Forest
- Oil Creek State Park
- Hillman State Park
- Marcellus Site (private land)
Marcellus Site

Airborne Magnetic Survey

Map of Well-Type Magnetic Anomalies

Navigating to Magnetic Anomaly Location

Locating Magnetic Anomaly on the Ground

Excavation to Confirm Well Location
Marcellus Site

Helicopter Magnetic Map of Proposed Marcellus Well Pad Location

Horizontal wells (proposed)

Total Magnetic Intensity

53500 nT

53000 nT

Marcellus Wellpad

Pipeline

250 Meters

250
How Accurate are Well Databases?

- PA IRIS database well positions often > 100 m from actual well locations
- 17 wells located in study area; six were in PA IRIS well database
- Some locations in PA IRIS not close to any confirmed well
Hillman State Park

Survey Statistics

- 17.7 km²
- 416419 samples (both sensors)
- 622.1 line-km
- Altitude 46.1 m AGL
  - (range: 22.3-166.2 m, sigma: 10.5 m)
Subdued intensities of Well-type Magnetic anomalies within the surface-mined areas
Hillman State Park

Depth from present day Surface to bottom of Pittsburgh #8 coal seam
Hillman State Park

Five Points, PA

Fill Area

Cut Area

Well Locations

WPA 23
WPA 24
Hillman State Park

Site 112

Buried wells in surface-mined areas
Hillman State Park

Site 112. Open wellbore

Oilfield artifacts

Hand forged “cut nails”

go devil

cable

paraffin

Board fragments
Hillman State Park

Ground magnetic survey and resistivity Array location over a buried well

Resistivity Survey in remediated surface-mined area

2D resistivity inversion model for estimating depth to buried well casing
Oil Creek State Park

Survey Statistics

- 37.7 km²
- 786505 samples (both sensors)
- 1244.6 line-km
- 51.0 m AGL
  - (range: 17-174 m, sigma: 9.2 m)
Oil Creek State Park

High Well Density

Unresolved Aeromagnetic Targets

Ground Magnetic Survey

100 m

Aeromagnetic

Drake Well 1859

Survey Track

Aeromagnetic Ground

Untargeted wells

Calculated Vertical Gradient

Analytic Signal

Total Magnetic Intensity
Oil Creek State Park

Pioneer Run, 1865

Unplugged, open Wellbore
Excavated 2016

Octagonal wood casing

Aeromagnetic Survey

Numerous Undetected wells

Pioneer Run, July, 2016

100 m
Oil Creek State Park

Pioneer Run Area, Oil Creek State Park
LiDAR 3-D perspective view
Oil Creek State Park
# Summary of Results

<table>
<thead>
<tr>
<th>Flight Area</th>
<th>Spud Dates</th>
<th>Recorded Wells</th>
<th>Found Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marcellus Site</td>
<td>1900-1925</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Hillman State Park</td>
<td>1880-1900</td>
<td>33 *</td>
<td>100+ **</td>
</tr>
<tr>
<td>Susquehannock SF</td>
<td>Post-1950</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>Oil Creek State Park</td>
<td>1859-1990</td>
<td>323</td>
<td>767+</td>
</tr>
</tbody>
</table>

*The 33 recorded well locations in PAIRIS were found to be offset an average of 73 meters when compared to the well location for the nearest site found in the aeromagnetic survey.*

**19 wells were found to be leaking methane**
Current and Future Work

**Issues:**
- Stability
- Payload
- Power consumption
- Induced magnetic noise
- Mission Endurance
- Terrain compliance
- Costs

Magnetometer console

Conventional cesium sensor
Current and Future Work
Micro Fabricated Atomic Magnetometer

- Small size: 15 cm³ sensor and 200 cm³ electronics
- High performance: ~ 1pT/√Hz noise, 1 KSps (GPS Sync), 400 Hz BW
- Low power operation: 2.5W / sensor nominal

- Light Weight:
  Each Sensor: 25 g, Electronics Module: 190 g
- Customizable interface for multi-sensor applications
- Auxiliary inertial measurement sensors
- Dead Zone: Polar, ± 30º

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Collaborations

- PA Department of Environmental Protection
- Geometrics Inc.
- RZI Drone Operators
- Spatial Analytics Inc.
- US Aerial Video Inc.
Accomplishments to Date

– Won an R&D 100 award in 2007
– Method successfully located wells in Oil Creek State Park, the oldest wells in the world and the most difficult to locate.
– Performed aeromagnetic surveys over 4 sites for purpose of locating legacy wells and improving existing databases in the context of streamlining permitting process and reducing environmental impacts associated with unconventional O&G development.
– Processed, mapped and cataloged aeromagnetic data for selected well targets using complimentary geophysical methods/modeling and fugitive methane measurements.
Accomplishments to Date

– Performed ground reconnaissance of selected targets and validation by ground magnetic method.
– Amend PA-IRIS wells database for Study Areas
– Established a well characterized test site (Hillman State Park, PA) having unique sets of challenges for well finding that will be used to evaluate miniature geophysical sensors aboard UAS platforms.
– Located and evaluated candidate unplugged well locations for fugitive methane emissions monitoring
– Bench testing of MFAM. Composed software to read and parse MFAM binary data, and perform custom TCP communications with microprocessor/controller for data acquisition and logging.
Synergy Opportunities

– Established partnership with PA Department of Environmental Protection/DCNR for access, data sharing and for purpose of monitoring and characterization of legacy well sites on State lands.

– Established partnerships with RZI Drone Operators, US Aerial Video, Inc., and Spatial Analytix, Inc. for the development and testing of unmanned aerial platforms carrying miniaturized magnetic sensors and photogrammetric imaging/terrain modeling.

– Established collaboration with Geometrics, Inc. and acquired a prototype MicroFabricated Atomic Magnetometer (MFAM) for bench testing and evaluation. MFAM was developed by under a DARPA grant.
Summary

– Findings - Developed rapid and effective methods to locate wells with steel casing; currently working on promising method to locate wells where casing is missing.
– Lessons Learned – Survey design parameters
– Future Plans – Use of UAV platforms to decrease cost
Organization Chart

• Describe project team, organization, and participants.
  – All work performed by NETL’s Field Monitoring Team except helicopter surveys, which were performed by an airborne geophysical contractor
## Gantt Chart

<table>
<thead>
<tr>
<th>Phase</th>
<th>Duration</th>
<th>Funding</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2005-2007</td>
<td>Carbon Storage</td>
<td>Two oilfields surveyed in WY; R&amp;D 100 Award</td>
</tr>
<tr>
<td>2</td>
<td>2012-2014</td>
<td>EPAct Section 999</td>
<td>4 Large areas surveyed in PA</td>
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</table>
Bibliography

Sams, J.I.; Veloski, G.A.; Hammack, R.W.; Diehl, R.J., 2016, Methods and Challenges to Locating Legacy Wells in Western PA: Case Study at Hillman State Park: Environmental Geosciences (a peer-reviewed AAPG Journal, Accepted for publication, In Press).


